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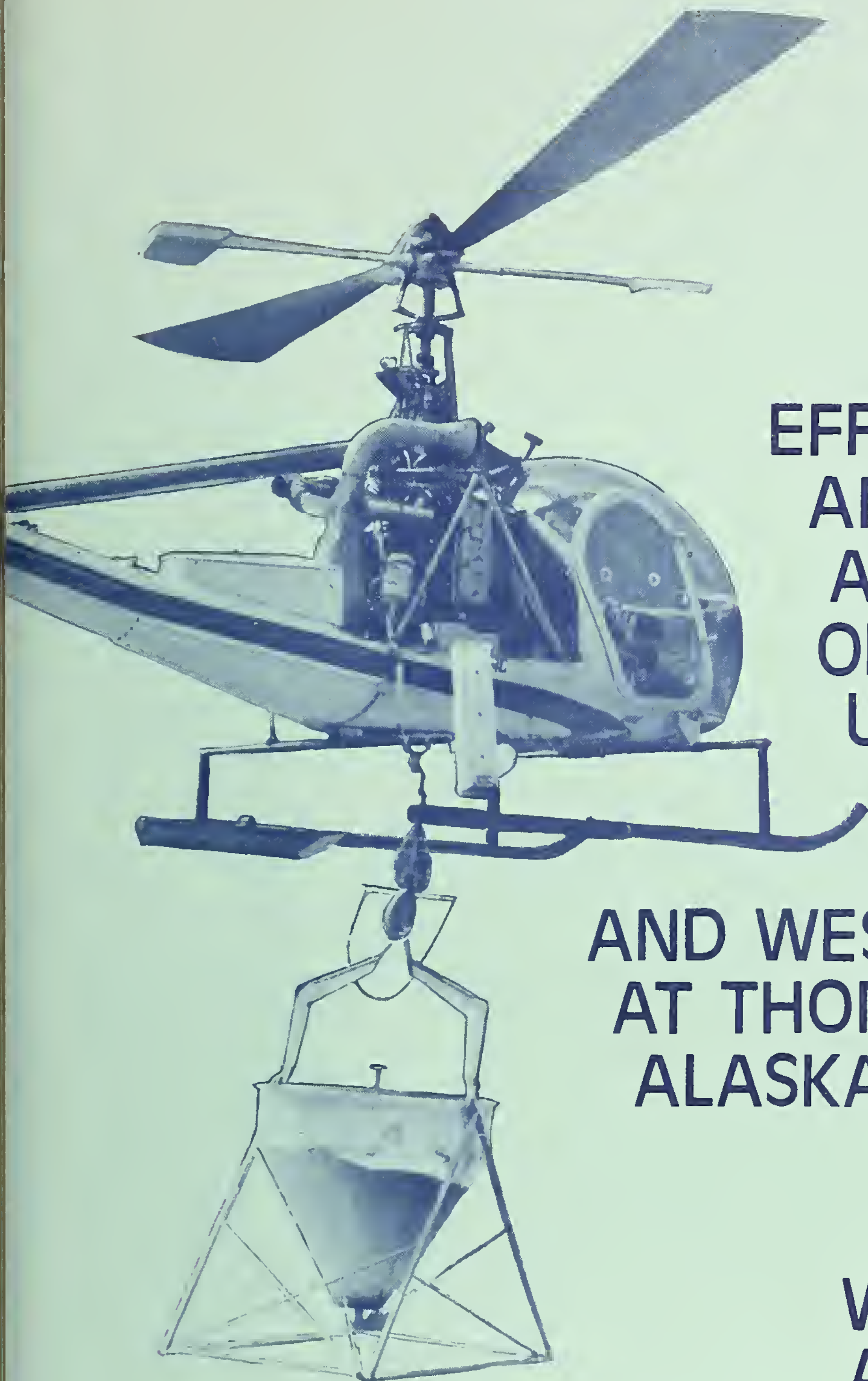

EFFECTS OF AN AERIAL APPLICATION OF UREA FERTILIZER ON YOUNG SITKA SPRUCE AND WESTERN HEMLOCK AT THOMAS BAY, ALASKA

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Effects of an Aerial Application of Urea Fertilizer on Young Sitka Spruce and Western Hemlock at Thomas Bay, Alaska.

Reference Abstract

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In May 1969, about 1,500 acres (607 ha) of 6- to 10-year-old western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) were fertilized with agricultural grade urea at the rate of 400 pounds of urea per acre (448 kg/ha). No response in growth was detected the 1st year, but concentrations of nitrogen in the foliage about doubled. By 1971, nearly all hemlock on the fertilized and unfertilized areas was suffering from tip and leader dieback caused by the fungus *Sirococcus strobilinus*. Because of the fungus, hemlock growth could not be evaluated. Height and diameter growth of spruce increased 20 to 30 percent the second growing season. By the 5th or 6th year, there was little difference in growth, the net effect being that fertilized spruce were then about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than similar unfertilized trees.

KEYWORDS: Nitrogen fertilizer response, fertilizer (-natural regeneration, regeneration (natural), fertilizer application methods, spraying (aerial), increment (height), increment (diameter), Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, fungi (-forest damage, *Sirococcus strobilinus*.

RESEARCH SUMMARY

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Encouraging results from small-plot trials treated with nitrogen fertilizer led to pilot projects from which experience was gained in costs, logistics in remote areas, and methods of applying fertilizer. One project took place on a glacial outwash plain at Thomas Bay, Alaska, where the effects of fertilization on tree growth were also assessed. Hemlock and spruce averaged 4 to 7 feet (1.2 to 2.1 m) in height, and all areas were stocked with 3,000 to 6,000 stems per acre (7 413 to 14 826/ha). Soils, which developed following glacial retreat, were relatively youthful and essentially well drained.

In May 1969, 310 tons (281 metric tons) of agricultural grade urea fertilizer was aerially applied by helicopter to four cutover units totaling about 1,500 acres (607 ha). The reported cost was $38.70 per acre ($95.63/ha). Height growth was measured annually through 1974. Foliage samples were also collected and analyzed in 1969, 1972, 1973, and 1974; and an analysis was made of annual diameter growth for the years 1966 through 1973.

There was no diameter or height response the first growing season although the concentration of nitrogen in the foliage of fertilized hemlock

and spruce was about twice that in unfertilized trees. By the third growing season after fertilization, most hemlock was infected with the fungus *Sirococcus strobilinus*. Both fertilized and unfertilized hemlock were equally affected. No analysis was made of the growth of hemlock because repeated tip and leader dieback greatly affected hemlock development. Spruce was not affected by dieback.

Height and diameter growth of spruce increased 20 to 30 percent the second growing season but declined thereafter. By 1973 or 1974, there was little difference in growth between fertilized and unfertilized trees of similar size. At the end of the study, the fertilized trees measured about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than they would have been had they not been fertilized. Although there were immediate results in terms of stand appearance and growth response, the fertilizer did not produce long-lasting results.

For now, we would not encourage additional large-scale applications of fertilizer. Instead, more basic information is needed on the nutrient requirements of hemlock and spruce and the effect of soils on fertilizer response. Information is not available on the results of fertilizing young stands growing on better developed upland soils.

Contents

Introduction

During the 1960's, a growing interest in forest fertilization developed throughout the world. This interest was prompted by diminishing supplies of timber and increasing demand for wood. Research focused on problems of tree nutrition and opportunities for improving yields through fertilization. A compilation of world literature from 1957 through 1964 included 1,215 publications pertaining to forest fertilization research (Mustanoja and Leaf 1965).

In the Pacific Northwest, interest in forest fertilization can be traced back to about 1950 when fertilizer trials were begun in immature Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands in western Washington (Gessel et al. 1969). Results were encouraging enough that by the mid-1960's private timber companies in the Pacific Northwest and Canada were aerially applying nitrogen (N) in the form of urea over many thousands of acres (Clark 1967, Forbes 1966).

Although most attention in the Pacific Northwest has been on Douglas-fir, considerable interest has also been shown in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). By 1975, fertilizer trials had been established on about 1,000 hemlock plots (DeBell 1975, DeBell et al. 1975).

In the case of Sitka spruce (*Picea sitchensis* (Bong.) Carr.), little experience has been gained in the United States although a great deal of work has been done in Great Britain. Extensive studies on the nutrition of Sitka spruce, mainly in nurseries, date back to the 1950's (Benzian 1965). By the mid-1960's, large areas of immature stands of Sitka spruce had been aerially fertilized in Scotland (Davies 1967, 1969).

Most emphasis on fertilization research has been on growth and yield of stands, but the environmental effects of large-scale fertilization have also received attention. A state-of-the art review with a description of environmental effects of fertilization was prepared in 1972: 52 studies were cited (Groman 1972).

Interest in forest fertilization in southeast Alaska developed in the 1960's. Forest soils were found to be deficient in available nitrogen, and small plot trials showed that added nitrogen significantly increased the growth of western hemlock and Sitka spruce (Johnson 1970).

Encouraging results from these trials prompted the U.S. Forest Service to test large-scale aerial applications of urea in young stands of hemlock-spruce. The projects summarized below were undertaken mostly to gain experience in methods, costs, and logistics of large-scale applications in remote areas, (Johnson 1970, Bowkett 1969):

Year	Location	Area in acres (hectares)	Age of regeneration in years
1969	Thomas Bay	1,500 (591)	6-10
1970	Mitkof Island	1,500 (591)	5-10
1971	Prince of Wales Island	1,500 (591)	6-10
1972	Kosciusko Island	930 (366)	15

Scattered cuttings at each location were fertilized by helicopter with urea prills (46-percent nitrogen by weight) at a rate of 400 pounds per acre (448 kg/ha).

In addition to experience gained on application costs and problems, effects of fertilization have been studied at two of the four sites. At Falls Creek on Mitkof Island, Meehan et al. (1975) found an initial short-term increase in ammonia-nitrogen in one stream, apparently from the direct application of fertilizer. The concentration never exceeded 1.28 mg/liter, a concentration well below that considered toxic to aquatic life. Concentrations of nitrate nitrogen in both streams remained higher than normal during a 1-year sampling period but never exceeded 2.36 mg per liter, far below the upper limits for human consumption defined as 10 mg per liter if reported as N and 45 mg per liter if reported as NO_3^-.

Foliar analysis of western hemlock and Sitka spruce and height and diameter growth of individual spruce trees were studied at Thomas Bay and are reported here. Western hemlock was severely diseased by the fungus *Sirococcus strobilinus* so a meaningful analysis of its growth was not possible.

Fertilizer Application

In May 1969, 310 tons (281 metric tons) of agricultural grade urea fertilizer was aerially applied by helicopter to four cutover units (totaling about 1,500 acres or 607 ha) at Thomas Bay (fig. 1).

Spreader-hoppers were used to distribute urea (fig. 2). Average flying distance from helispots to the project area was about 1 mile (1.6 km).

Agricultural grade urea prill was used because larger size forestry grade was not obtainable. This limited the effective swath width to 30-40 feet (9-12 m) and increased the cost of application.[1/]

Fertilizer traps, 4 square feet (0.37 m^2) in area, placed throughout the fertilized units, indicated that the fertilizer was well distributed although no analysis was made of the distribution. Costs for the project averaged \$38.70 per acre (\$95.63/ha) (see footnote 1).

[1/] Information on file at Forestry Sciences Laboratory, Juneau, Alaska.

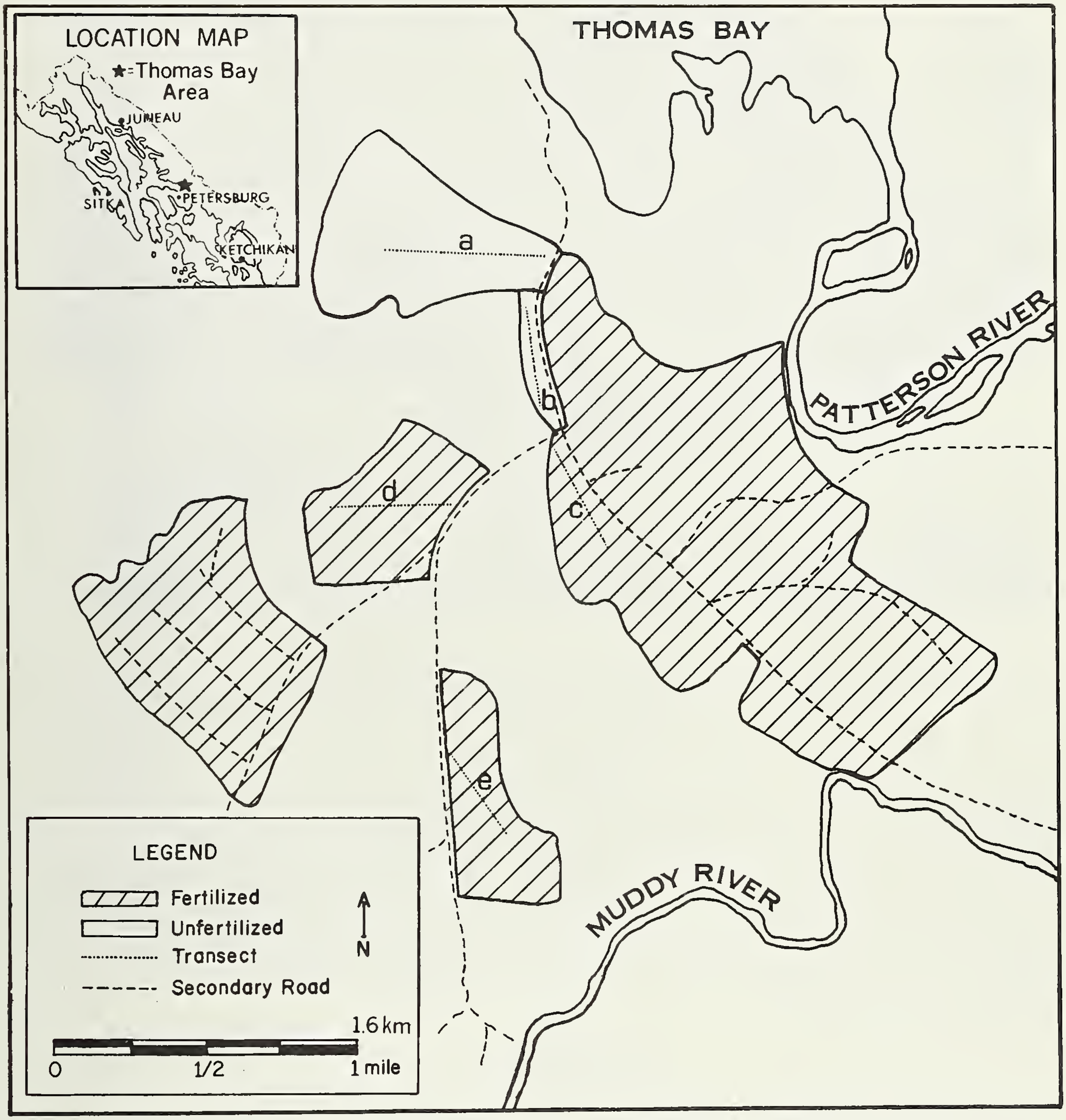

Figure 1.--Fertilized and unfertilized stands and location of sample transects at Thomas Bay, Alaska.

Figure 2.--Loading urea fertilizer in spreader-hopper for aerial application by helicopter, Thomas Bay, Alaska.

The fertilized units were located on a glacial-outwash plain in front of Patterson Glacier. Soils are relatively youthful, having developed after glacial retreat. The soils are generally excessively well-drained, coarse sands and coarse sandy loams. They do not exhibit thixotropic properties common to most mature soils in southeast Alaska because of their low levels of incorporated iron and humus. The area is somewhat unusual in that outwash plains this large are not as common as other soil types in southeast Alaska. Therefore, results of this study apply only to similar conditions. Before logging, cutover units supported mature mixed stands of western hemlock and Sitka spruce averaging 46,000 board feet per acre ($\sim$647 m^3 per hectare).

Methods

In the fall of 1969, sample trees were selected in fertilized and unfertilized units so growth response to fertilization could be measured. Spruce and hemlock regeneration averaged 5 to 8 feet (1.5-2.4 m) in height, and all areas were stocked with 3,000 to 6,000 trees per acre (7,413 to 14,826/ha). Because trees were small and crown closure was not complete (fig. 3), volume response on an area basis could not be measured. Instead, height and diameter growth of individual trees were measured.

Figure 3.--At the time of fertilization, the stand averaged 4 to 7 feet in height, with 3,000 to 6,000 stems per acre.

A 20-chain transect was run through each of three fertilized units and through two unfertilized units (fig. 1). At 66-foot (20-m) intervals along each transect, the nearest dominant spruce and hemlock were selected as permanent sample trees--20 trees of each species. Total height, current year's growth, and annual height growth for the 3 years before fertilization were recorded. At the same time, a sample of the current year's foliage was clipped from the upper third of the crown of each tree.

Air drying of the foliage began immediately after collection. Within 3 to 5 days, all samples were ovendried at 149-158 °F (65-70 °C) for 24 hours. Foliage was removed from twigs, and ground in a Wiley[2/] mill to pass a 40-mesh screen, and bagged in transparent plastic envelopes for later analysis.[3/]

We noticed that color differences were apparent in the foliage samples, so two independent observers compared the dried ground samples with standard Munsell color chips (Munsell 1963) in a laboratory well illuminated by fluorescent lights. The Munsell color chips were viewed through plastic similar to that enclosing the samples. Results from the two observers were then compared and any differences resolved by a third observer. Additional foliar samples were taken after the fourth, fifth, and sixth growing seasons.

Annual height growth of all hemlock and spruce sample trees was measured each fall from 1969 through 1974.

2/ Mention of products by name does not constitute an endorsement by the U.S. Department of Agriculture to the exclusion of other products which may be suitable.

3/ Foliar nutrient concentrations were determined after the first and fourth growing seasons by the Department of Soils, University of Alaska, after the fifth season by the Department of Forest Soils, Washington State University, and after the sixth season by the University of Washington.

In the fall of 1973, five growing seasons after fertilization, sample trees were felled and sectioned so diameter development could be measured. A dominant spruce of comparable height and diameter was selected within 33 feet (10 m) of each sample spruce tree; these trees were felled instead of the trees used to measure annual height growth. These were felled and sectioned at 2 and 4.5 feet (0.6 and 1.4 m) above ground. Moist cross sections were stored in plastic bags at a cool temperature, and annual radial growth was determined in the laboratory from averages of measurements across each of four diagonals for the years 1966 through 1973.

Statistical analysis of the test results was complicated by too few replications (three areas of fertilized and two of control), plus the fact that the observations were not independent (i.e., the same trees were remeasured several years). Also, because of the variation in tree size, mean growth of trees in fertilized and unfertilized areas could not be directly compared. Therefore, we used analysis of covariance fitting a linear relationship between height growth and total height for each area. Height growth between fertilized and unfertilized trees was compared by testing for differences between selected curves. A similar analysis was used for diameter growth with diameter as a covariate. From this, we drew general conclusions, being careful not to place emphasis on any single test as conditional testing affects the probability involved in each test. The reader should keep these statistical limitations in mind when interpreting results.

When the initial measurements were made in the fall of 1969, both hemlock and spruce were tagged for future remeasurement and all appeared healthy. By the fall of 1970, however, many hemlock appeared to be suffering from a tip and leader dieback. This cause was later identified as the fungus *Sirococcus strobilinus*. This fungus, reported on young hemlock in Canada (Funk 1972), occurs at several locations in southeast Alaska.

By fall 1971, nearly all hemlock on both fertilized and unfertilized units appeared to be affected by the fungus; it was apparent that the growth response of western hemlock could not be evaluated. The fungus was not detected on any of the spruce sample trees. Therefore, analysis of growth has been confined to the spruce component of the stand. Fertilization does not appear to have increased susceptibility of hemlock to attack by this fungus as both treated and untreated areas were equally affected.

Results

HEIGHT GROWTH

Height growth of fertilized Sitka spruce increased 20 to 25 percent during the second growing season after fertilization; no difference was detected the 1st year.

Before fertilization, mean tree height ranged from 4 to 7 feet (1.2 to 2.1 m) on the five areas and ages ranged from 5 to 11 years (table 1); this complicated the analysis.

Before fertilization there were no significant differences in height growth between areas for trees of similar height (table 2). The same was true for 1969, the first growing season after fertilization. In the second growing season (1970), height growth of fertilized trees was significantly greater for the range of heights sampled.

Table 1.--*Mean total height of Sitka spruce at Thomas Bay, Alaska, by area and year*

Area	Age at end of 1968	Before fertilization			After fertilization					
		1966	1967	1968	1969[1]	1970	1971	1972	1973	1974
	Years	Feet								
Unfertilized:										
A	5	1.88	2.58	3.57	4.55	5.51	6.49	7.59	8.67	9.71
B	11	2.70	3.55	4.62	5.77	6.82	8.01	9.32	10.64	11.86
Mean	8	2.29	3.07	4.10	5.16	6.17	7.25	8.46	9.66	10.79
Fertilized:										
C	9	2.95	3.93	5.09	6.22	7.67	9.16	10.69	12.28	13.67
D	6	4.34	5.38	6.83	8.08	9.87	11.58	13.45	15.36	17.04
E	6	2.77	3.63	4.79	6.11	7.57	9.14	10.98	12.76	14.17
Mean	7	3.35	4.31	5.57	6.80	8.37	9.96	11.71	13.47	14.96

1/ Fertilizer was applied in May.

Table 2.--*Analysis of covariance "F" values[1] for tests of differences in height growth before and after fertilization at Thomas Bay, Alaska*

Area comparisons[2]	Before fertilization		After fertilization					
	1967	1968	1969	1970	1971	1972	1973	1974
A versus B	0.02	0.92	0.31	0.70	0.04	0.04	3.91	0.04
A versus C	.82	0	0	4.54*	2.98	.38	2.50	1.22
A versus D	1.53	.03	1.21	8.22**	3.95	1.06	1.28	1.46
A versus E	.05	0	3.13	10.70**	5.48	6.35*	4.94*	.50
B versus C	.07	.09	.01	4.50*	2.44	.31	.58	.99
B versus D	2.28	.32	.71	8.20**	4.25*	5.93*	3.40	.04
A + B versus C+D+E	1.73	.11	1.22	17.80**	9.23**	4.42*	4.21*	.70

1/ In the analysis of covariance two null hypotheses were tested: (1) that the simple regression lines were parallel and (2) that the adjusted means were equal, where Y=height growth in year i and X=total height at the end of year i-1.

Hypothesis 1 was accepted in all cases, and "F" values are not shown; "F" values for hypothesis 2 are given.

2/ Areas C, D, and E were fertilized; areas A and B were not fertilized.

* Significant at the 5-percent level of probability.

** Significant at the 1-percent level of probability.

In the years following 1970, the benefits of urea fertilization appeared to lessen; by 1974 there were no significant differences in height growth of fertilized and unfertilized trees.

DIAMETER GROWTH

At the time of fertilization, many sample trees had not yet reached breast height. Therefore, diameter growth was compared at a height of 2 feet (0.6 m) above the root collar (table 3).

Before fertilization, the relationship between diameter growth and diameter was similar for all areas (table 4). With one exception, the same was true in 1969, the first growing season after fertilization. In 1970 and 1971, the fertilized trees showed for most comparisons a highly significant response to fertilization. On a percentage basis the response was about 25 to 30 percent. Response appeared to decline after 1971, and by 1973 there were indications that differences in growth rates were once again at or near the level of nonsignificance.

Table 3.--Mean diameter 2 feet above the root collar of Sitka spruce at Thomas Bay, Alaska, by area and year

Area	Before fertilization				After fertilization				
	1965	1966	1967	1968	1969	1970	1971	1972	1973
	Inches								
Unfertilized:									
A	0.13	0.26	0.45	0.68	0.92	1.20	1.50	1.79	2.10
B	.26	.39	.55	.73	.94	1.18	1.45	1.73	2.05
Mean	.20	.33	.51	.71	.93	1.19	1.47	1.76	2.07
Fertilized:									
C	.23	.38	.55	.75	.96	1.28	1.63	1.99	2.39
D	.39	.56	.76	.99	1.29	1.68	2.10	2.46	2.86
E	.13	.23	.40	.59	.83	1.17	1.54	1.90	2.28
Mean	.25	.39	.57	.78	1.02	1.38	1.76	2.11	2.51

Table 4.--Analysis of covariance "F" values[1] for tests of differences in diameter growth before and after fertilization at Thomas Bay, Alaska

Area comparisons[2]	Before fertilization						After fertilization									
	1966		1967		1968		1969		1970		1971		1972		1973	
	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means	Slopes	Adjusted means
A versus B	3.19	0.40	1.18	1.89	0.12	5.63*	0.42	1.70	0.24	1.63	0	0.71	0	0.14	0	0.12
A versus C	1.75	.24	.26	.60	.06	1.17	.13	2.53	.43	1.53	.12	1.46	.22	2.53	.30	4.64*
A versus D	.74	1.45	.38	.11	.11	.08	.39	2.13	0	3.97	.56	2.01	.31	.63	.44	.63
A versus E	2.07	.93	2.17	.60	.46	.99	.56	.15	5.58*	5.94*	3.80	3.06	3.42	3.20	2.29	3.92
B versus C	.37	2.34	.38	.22	.73	1.67	.19	.04	.74	9.19***	.48	10.1***	.34	5.05*	.42	4.01
B versus D	2.02	3.79	.46	.88	1.00	3.69	0	10.70***	.34	16.6***	1.33	10.9**	.53	1.87	.65	.28
B versus E	.21	.05	1.09	.26	.39	1.20	3.23	3.33	15.60***	16.10***	9.85***	12.30***	5.74*	5.66*	3.28	2.50
A+B versus C+D+E	.35	.39	.32	.02	.01	.12	.51	1.48	1.14	16.2***	2.00	12.1***	.71	6.46*	.64	5.12*

1/ In the analysis of covariance two hypotheses were tested: (1) that the slopes of the simple regression lines were equal and (2) that the adjusted means were equal, where Y=diameter growth in year i and X=diameter at the end of year i-1.

2/ Areas C, D, and E were fertilized; areas A and B were not fertilized.

* Significant at the 5-percent level of probability.

** Significant at the 1-percent level of probability.

*** Significant at the 0.5-percent level of probability.

FOLIAR NUTRIENT CONCENTRATIONS

Foliage collected from each sample tree in 1969 was analyzed separately, and means and standard errors were computed for each nutrient by area. In 1972, 1973, and 1974, foliage from the sample trees was mixed as a composite sample so estimates of variation are not available.

After the first growing season following fertilization (1969), there were significant differences between percent nitrogen in fertilized and unfertilized hemlock and spruce (tables 5 and 6). After four growing seasons (1972), concentrations of N in spruce were about the same. In hemlock, the concentrations of N, though not significant, were generally higher in fertilized trees until 1974 when the levels were slightly higher in unfertilized trees.

Table 5--*Mean nutrient concentrations in the foliage of Sitka spruce at Thomas Bay, Alaska*[1/]

Area and year	Dry matter concentrations						
	N	P	K	Ca	Mg	Mn	Zn
	Percent					Parts per million	
Unfertilized:							
A--1969	1.18a	0.16a	0.45a	0.26a	0.065ab	465a	29a
1972	.99	.17	.54	.31	.096	--	--
1973	.90	--	--	--	--	--	--
1974	.94	--	--	--	--	--	--
B--1969	1.26a	.16a	.46a	.31a	.063ab	424a	26a
1972	1.06	.19	.62	.37	.092	--	--
1973	.86	--	--	--	--	--	--
1974	1.07	--	--	--	--	--	--
Fertilized:							
C--1969	2.57b	.18a	.44a	.29a	.053b	442a	17b
1972	.99	.16	.60	.28	.084	--	--
1973	1.06	--	--	--	--	--	--
1974	1.06	--	--	--	--	--	--
D--1969	2.25b	.18ab	.44a	.28a	.056ab	408a	26a
1972	.99	.17	.51	.29	.081	--	--
1973	.95	--	--	--	--	--	--
1974	1.05	--	--	--	--	--	--
E--1969	2.47b	.21b	.50a	.30a	.066a	428a	27a
1972	1.14	.18	.64	.34	.084	--	--
1973	.97	--	--	--	--	--	--
1974	.99	--	--	--	--	--	--

[1/] Values are averages for 20 samples obtained from 20 trees. Values for 1969 in each column followed by the same letter are not significantly different (Tukey test, $P<0.05$). -- = no data.

Table 6--*Mean nutrient concentrations in the foliage of western hemlock at Thomas Bay, Alaska*[1/]

Area and year	Dry matter concentrations						
	N	P	K	Ca	Mg	Mn	Zn
	- - - - - - - - - -	- - - - - - - - - -	Percent	- - - - - - - - - -	- - - - - - - - - -	Parts per million	
Unfertilized:							
A--1969	1.31a	0.23a	0.49a	0.21ab	0.088a	558a	21a
1972	.98	.23	.64	.26	.146	--	--
1973	.98	--	--	--	--	--	--
1974	1.00	--	--	--	--	--	--
B--1969	1.34a	.20a	.57ab	.24b	.088a	600a	14b
1972	.91	.23	.72	.28	.144	--	--
1973	1.08	--	--	--	--	--	--
1974	1.13	--	--	--	--	--	--
Fertilized:							
C--1969	2.12b	.21a	.58b	.19ac	.074ab	530a	23a
1972	1.31	.25	.69	.22	.124	--	--
1973	1.16	--	--	--	--	--	--
1974	1.02	--	--	--	--	--	--
D--1969	2.24b	.24a	.52ab	.17c	.070b	524a	26a
1972	1.21	.23	.58	.25	.128	--	--
1973	1.28	--	--	--	--	--	--
1974	.87	--	--	--	--	--	--
E--1969	2.19b	.23a	.59b	.21abc	.078ab	581a	21ab
1972	1.06	.19	.64	.28	.130	--	--
1973	1.20	--	--	--	--	--	--
1974	.96	--	--	--	--	--	--

[1/] Values are averages for 20 samples obtained from 20 trees. Values in 1969 in each column followed by the same letter are not significantly different (Tukey test, $P<0.05$). -- = no data.

For unfertilized trees, mean concentrations of N were higher on all areas in 1969 than in later years and concentrations varied from year to year. These variations may be the result of year-to-year response of trees to climate. After discounting these variations, we still noted that N in fertilized trees was twice that in unfertilized trees at the end of the first growing season after fertilization.

At the same time, concentrations of P, K, Ca, Mg, and Mn in fertilized trees were about the same as in unfertilized trees. Some means were significantly different, but definite trends were not apparent.

FOLIAR COLOR

The color of dried ground foliage of both hemlock and spruce differed between fertilized and unfertilized trees the first growing season after fertilization (fig. 4). Foliage of fertilized hemlock and spruce had a more greenish hue than did unfertilized samples; value was about the same but perhaps more variable in fertilized samples, and chroma tended to be lower (less intense) in fertilized than in unfertilized samples; in other words, greener, about as dark, and less intense. Color differences were not apparent in later years and comparisons made from Munsell charts were not recorded after the first growing season.

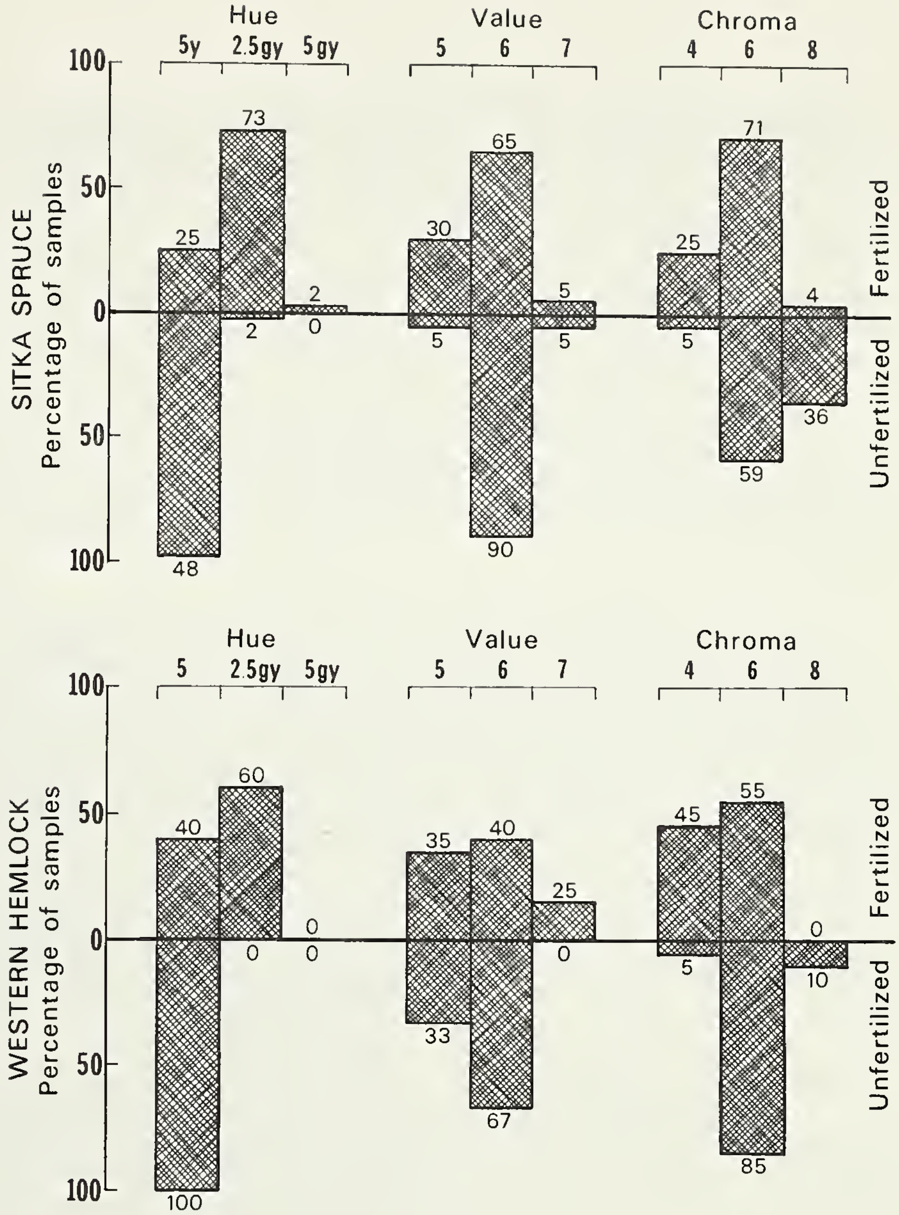

Figure 4.--Percentage of dried foliage samples by color (hue, value, chroma) on fertilized and unfertilized plots, Thomas Bay, Alaska, 1969 ("g" refers to green and "y" refers to yellow).

Discussion

Fertilizer was applied at Thomas Bay in May 1969 to stimulate growth of Sitka spruce and western hemlock by providing an increase in nitrogen, considered to be in short supply.

By fall 1971, it became apparent that the hemlock was heavily infected with the fungus *Sirococcus strobilinus* (Funk 1972) and that the response of hemlock to fertilization could not be evaluated. Prevalence of the disease was not associated with fertilization as both fertilized and unfertilized areas were equally infected.

At present the relationship between fertilization and incidence of disease is not well known. Apparently reactions differ, and no general statements can be made. Much additional experience and study will be necessary before the adverse or beneficial effects of fertilization on disease control can be determined (Hesterberg and Jurgensen 1972).

Application of 400 pounds per acre (448 kg/ha) of urea fertilizer resulted in increased height and diameter growth of Sitka spruce beginning in 1970, the second growing season after fertilization. The greatest

increase took place in 1970; thereafter, the response lessened and by 1973 or 1974, there was little difference in growth between fertilized and unfertilized trees of similar size. Average height growth was increased 20 to 25 percent and diameter growth 25 to 30 percent with decreased height growth in later years. In all, the beneficial effects of urea fertilization appeared to last about 4 years, at which time, fertilized trees were about 2 feet (0.6 m) taller and 0.5 inch (1.3 cm) larger in diameter than they would have been had they not been fertilized.

Response in terms of increased wood volume could not be evaluated because trees were small and only the growth of Sitka spruce was measured. Growth rates were increased for about 4 years. For this increase to be maintained, fertilization would have to be repeated at 4- to 5-year intervals.

Little is known about growth response of western hemlock to fertilization. Tests in the Pacific Northwest have produced mixed results. Best results have been obtained in the Washington Cascades, coastal Washington, and on Vancouver Island (DeBell 1975). The reasons for increased growth of hemlock are also not well understood, although an increase in leaf area and crown size with resulting efficiency in photosynthetic activity is thought to be important (DeBell 1975).

At Thomas Bay, concentrations of N and K were low in unfertilized trees (tables 5 and 6). Of major nutrients, K appeared to be in very short supply when compared with concentrations normally found in hemlock and spruce growing elsewhere on good sites (table 7).

Table 7--*Means and ranges (in parentheses) of nutrient concentrations of Sitka spruce and western hemlock in England and in the Maybeso Experimental Forest, Hollis, Alaska*

Species	Ovendry weight					Source
	N	P	K	Ca	Mg	
	- - - - - - -	- - - - - - -	Percent	- - - - - - -	- - - - - - -	
Sitka spruce:						
Good growth	1.59 (1.19-1.93)	0.22 (0.19-0.34)	1.27 (0.81-1.67)	0.35 (0.25-0.55)	0.14 (0.07-0.20)	Binns et al. 1970
	1.47 (1.07-1.76)	0.24 (.18- .33)	1.15 (.68-1.58)	.24 (.15- .40)	.12 (.09- .16)	Binns and Atterson 1967
	1.38 (1.05-1.66)	.22 (.13- .32)	.80 (.55-1.35)	.31 (.13- .56)	.09 (.06- .15)	1/
Poor growth	1.09 (.86-1.34)	.16 (.09- .27)	.88 (.52-1.15)	.43 (.36- .59)	.14 (.08- .25)	Binns et al. 1970
	.95 (.72-1.27)	.16 (.08- .19)	.69 (.30- .89)	.28 (.21- .37)	.10 (.08- .12)	Binns and Atterson 1967
	.88 (.69-1.12)	.15 (.10- .21)	.65 (.42- .92)	.31 (.14- .50)	.07 (.03- .10)	1/
Western hemlock:						
Good growth	1.28 (1.00-1.48)	.28 (.18- .34)	.68 (.26- .94)	.20 (.09- .34)	.13 (.09- .17)	1/
Poor growth	.83 (.60-1.02)	.18 (.09- .40)	.62 (.40- .82)	.17 (.08- .28)	.09 (.07- .14)	1/

1/ Data from the Maybeso Experimental Forest, Hollis, Alaska; on file at the Forestry Sciences Laboratory, Juneau, Alaska.

Concentration of nitrogen in foliage of fertilized trees was significantly higher than in unfertilized trees the first season after treatment but declined to lower levels within 3 years. Levels of other nutrients probably were not significantly affected by fertilization.

Our limited information relating nutrient concentration to growth in southeast Alaska makes it difficult to interpret the practical significance of nutrient values. Assessment of nutrient requirements for plants is imprecise. It is generally conceded that there is no single optimum level of concentration for each nutrient. Greenhouse experiments with Sitka spruce have shown that tree age and provenance affect nutrient concentrations in tissues of trees grown under the same supply of nutrients, and that the supply level of one nutrient may affect tissue concentration of several nutrients (van den Driessche 1969).

Sites at Thomas Bay have been deglaciated for only about 1,000 years, and soils are relatively youthful. Textures are stony, gravelly loamy sands with 50 to 90 percent coarse fragments estimated by volume. Soils are well drained. Organic matter is important as a medium of nutrient transfer from soils to plants as there is little clay or other colloidal material in the coarse mineral soil. The surface organic layer is shallow and where missing as a result of logging, tree growth is slow. Root systems and soil profile development are confined to the uppermost few inches of soil. We suspect that much of the nitrogen supplied by urea was leached out of the ecosystem within the first growing season or tied up in the surface organic layer. Lacking detailed chemical soil information, we can only speculate concerning the fate of applied urea.

Conclusions

Aerial fertilization is an attractive tool in forest management because large areas may be treated quickly at minimum effort, almost immediate results may be obtained in terms of appearance of a stand, and an early increase in growth may occur. Fertilization, however, may not produce an economical or lasting increase in growth on glacial outwash soils such as those at Thomas Bay. Information for other soil types is not available.

In areas where timber values are high, where stands are close to the mill, and where rotations are short, fertilization may be useful, especially when combined with thinning or other intensive cultural measures.

More basic information is needed on nutrient requirements of hemlock and spruce in Alaska and on the effects of soils on fertilizer response. Further investigation of environmental effects of fertilization is also indicated. Information on benefits versus costs of large-scale fertilization is essential. The recent severalfold increase in cost of fertilizers and the uncertainty of future supplies are focusing attention on economics.

In southeast Alaska where forest management is presently not intensive, large-scale forest fertilization does not now appear to be justified. We would not encourage large-scale applications of fertilizer until more is known about the potential for response. Instead, studies should be directed toward gaining knowledge of the potential for thinning, combinations of thinning and fertilization, and fertilization of older stands where increases in growth could be realized in a short time.

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KEYWORDS: Nitrogen fertilizer response, fertilizer (-natural regeneration, regeneration (natural), fertilizer application methods, spraying (aerial), increment (height), increment (diameter), Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, fungi (-forest damage, *Sirococcus strobilinus*.

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